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Title:	Updated Delayed Neutron Counting Test Suite Comparisons from RMCC and MCNP6 Version 1 Release
Author(s):	Sellers, Madison Beames-Canivet, T.L. Kelly, D.G. Corcoran, E.C. Goorley, John T.
Intended for:	Inclusion in M.T. Andrew's (Sellers) RMCC PhD dissertation. Update to files from RMCC in MCNP test suite. Report
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Title: Updated Delayed Neutron Counting Test Suite Comparisons from RMCC and MCNP6 Version 1 Release

Author(s): M.T. Andrews[1], T.L. Beames-Canivet[1], D.G. Kelly[1], E.C. Corcoran[1], J.T. Goorley[2]

[1] *Royal Military College of Canada, P.O. Box 17000 Stn Forces, Kingston, ON, K7K 7B4,*
[2] *Monte Carlo Codes, MS: A143, Los Alamos National Laboratory, Los Alamos, NM, 87545*

Intended for:

- An update to the released files contained within the MCNP6 Delayed Particle Test Suite.
- Inclusion in M.T. Andrew's RMCC PhD dissertation.

Accompanying Materials:

- 9 updated MCNP input decks simulating delayed neutron emissions from SNM.

Date: July 2014

Introduction

This brief report describes significantly updated versions of several delayed neutron files contained within the version 1 release of MCNP6. MCNP6.1 [1] simulations recreate the irradiation of milligram quantities of special nuclear materials (SNMs) in aqueous solutions for 60 *s*. Delayed neutron (DN) magnitudes and temporal behaviors are recorded with F1 tallies and compared to measurements at the Royal Military College of Canada. These comparisons are described in detail in reference 2. The three different DN options currently available in MCNP6v1(DN=model, DN=library and DN=both) were tested, for ^{233}U, ^{235}U (contained in Nat. U), and ^{239}Pu emissions up to 3 minutes after the elapse of irradiation. Also included in this report is a comparison of measurements with a modified MCNP6 executable containing an updated time-bin structure for DN=model option emissions.

Experimentation

Solutions containing ^{233}U, ^{239}Pu and natural uranium were prepared from certified reference material standards and further diluted with nitric acid and distilled water. Samples were placed in polyethylene vials before pneumatic transport to an inner SLOWPOKE-2 research reactor irradiation site where they were exposed to a predominately thermal neutron flux for 60 *s*. After irradiation the samples were sent to an array of ^{3}He detectors which recorded the DN emissions as a function of count time for up to 3 minutes. Further details regarding the delayed neutron counting system and these measurements can be found in references 2 and 3 respectively. Experimental data has been corrected for dead time effects and neutron background contributions [4]. **Measurements have been normalized by fissile mass [*g*] and detection efficiency (33 %) to obtain DN emission rate, *Q(t)* [$s^{-1}g^{-1}$].** Each isotope (^{233}U, ^{235}U, and ^{239}Pu) was irradiated and counted in triplicate; the provided measurements represent their average *Q(t)*. Plots with error bars included represent the 95 % confidence interval on measurements.

MCNP Simulations

Atomic Energy of Canada Limited has provided a MCNP input deck containing LEU SLOWPOKE-2 dimension and material specifications, the contents of which are detailed in reference 5. This input deck was modified to include a polyethylene vial within an inner irradiation site to determine a higher fidelity neutron flux spectrum. This flux was recreated within the vial solution of a second input deck, which includes the irradiation of a fissile solution for 60 *s* and the recording of subsequent DN emissions from the vial. The DN emission rate, *Q(t)* [$s^{-1}g^{-1}$], for each MCNP6v1 simulation was compared to the normalized measurements described in the previous section. The time-bin structure for the former was updated in a modified MCNP6 executable, MCNP6_dbf.exe[1]; its comparison is also presented.

[1] The MCNP6_dbf.exe was provided by M. James.

Comparisons

MCNP6v1 DN=model, library, and both comparisons

Measurements are now compared as DN emission rates, $Q(t)$ [$g^{-1}s^{-1}$]. Figure 1 compares the measurements of DN emissions for ^{233}U, and MCNP6v1 simulations using the three DN emission options. The DN=both option is omitted in subsequent comparisons because it is indistinguishable from the DN=library option. Figures 2-4 compare the DN emission rate for ^{233}U, ^{235}U (in Nat. U), and ^{239}Pu, using the DN=model and DN=library options in MCNP6v1.

MCNP6v1 with Delayed Bin Fix

Using the DN=model option in SNM simulations with MCNP6v1 resulted in a deviation from the measurements at approximately 100 *s*. This anomaly is eliminated by using MCNP6v1 with the delayed bin fix (DBF), as shown in Figures 5-7. Figures 8-10 compare the DN emission rates for ^{233}U, ^{235}U (in Nat. U), and ^{239}Pu, using MCNP6_dbf.exe for the DN=model option and MCNP6v1 for the DN=library option.

Summary

DN emissions from ^{233}U, ^{235}U, and ^{239}Pu were compared to MCNP6v1 simulations using the DN=model, both, and library options. Previously noted [2] time-dependent anomalies resultant from the use of the DN model option were noted and resolved with a modified MCNP6 executable containing an updated time-bin structure for DN emissions. Overall the model option (when used with the modified executable) yields the best agreement when compared to measurements from RMCC. Future work could include comparisons of measurements to MCNP simulations using MCNP6 1.1 Beta, which includes an option in the DBCN card for a more refined time-bin structure for delayed particle emissions [6].

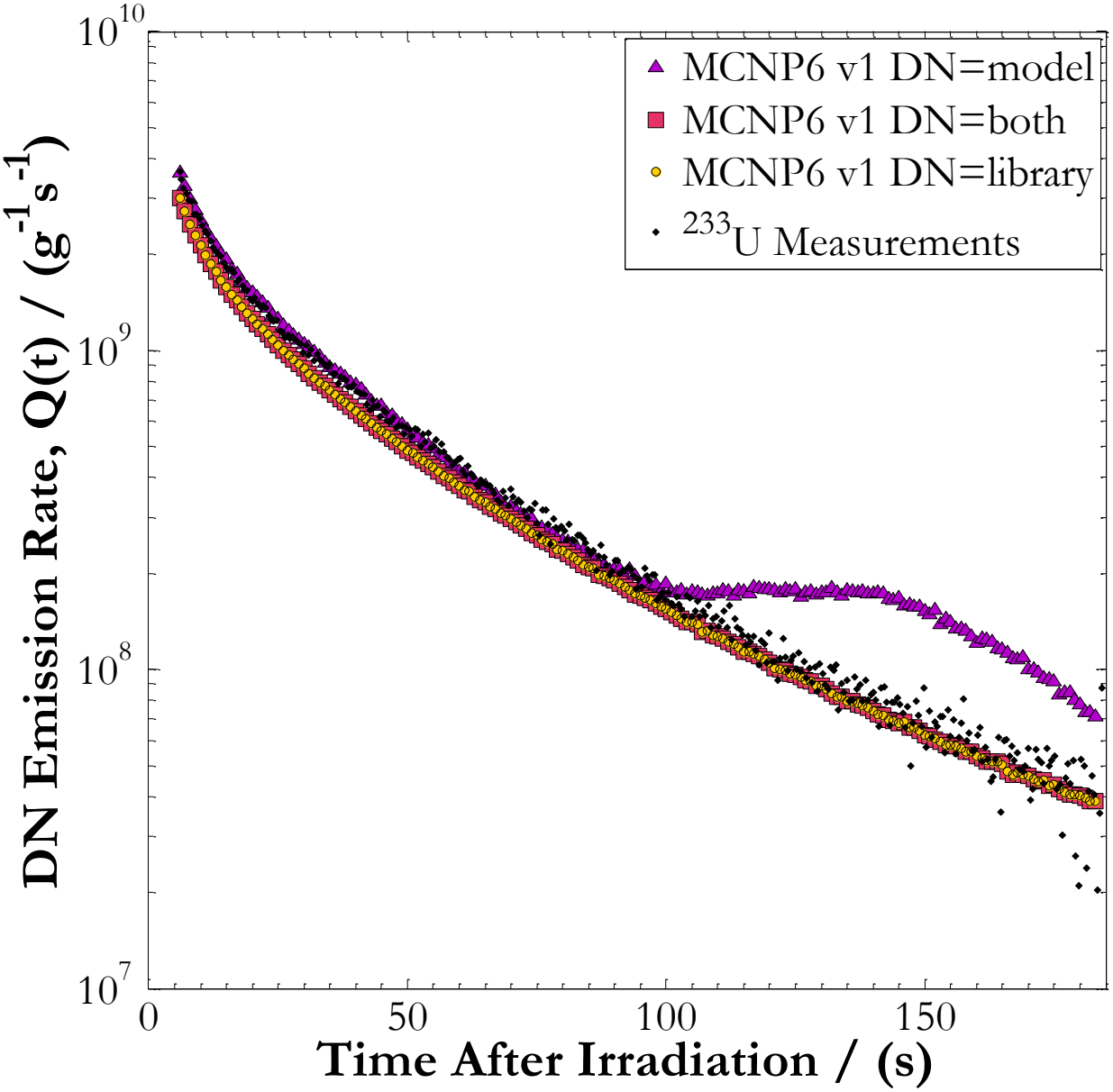

Figure 1: Delayed neutron emission rates from ^{233}U measurements, and three DN options in MCNP6v1 simulations.

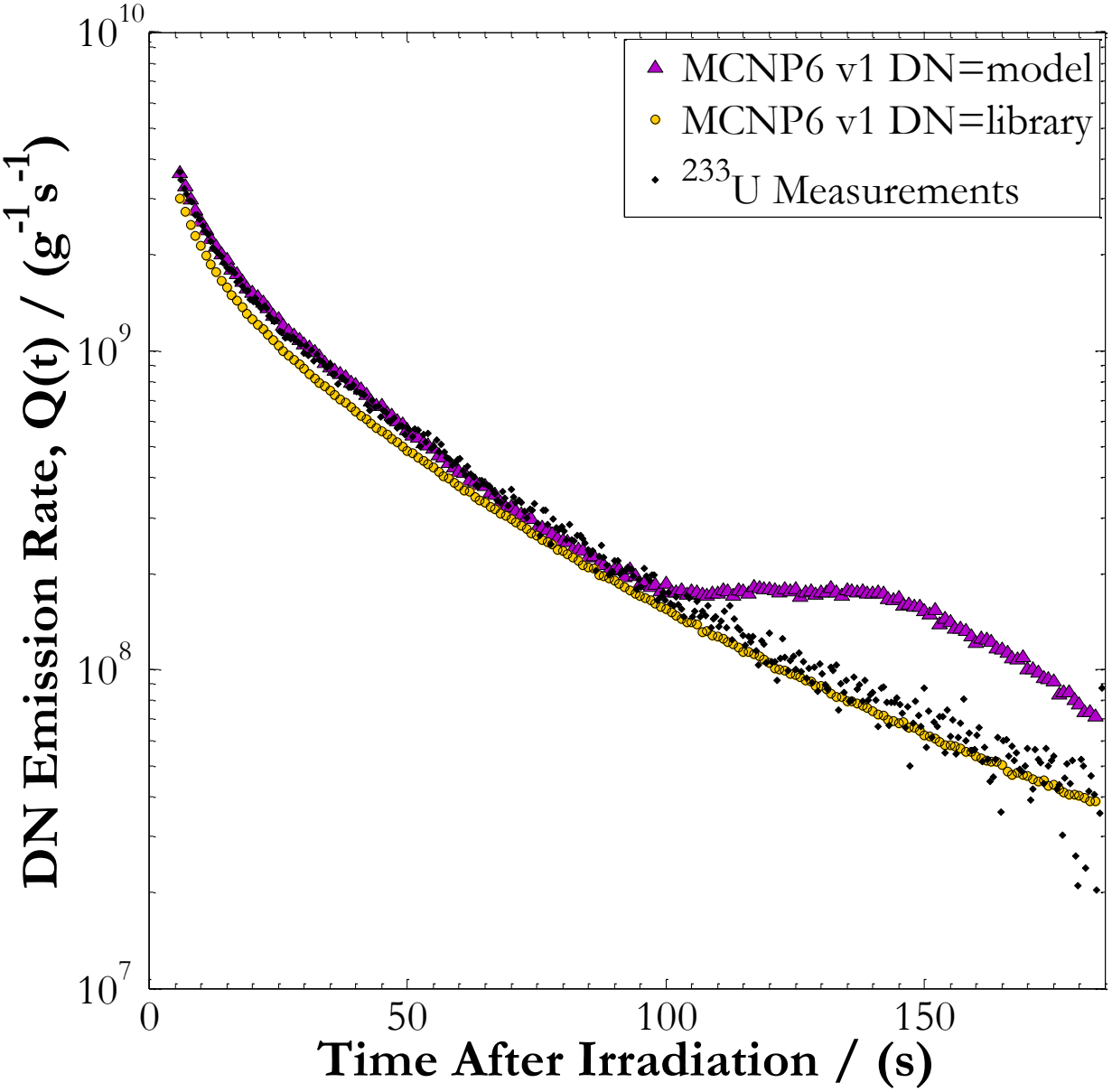

Figure 2: Delayed neutron emission rates from ^{233}U measurements, model and library DN options in MCNP6v1 simulations.

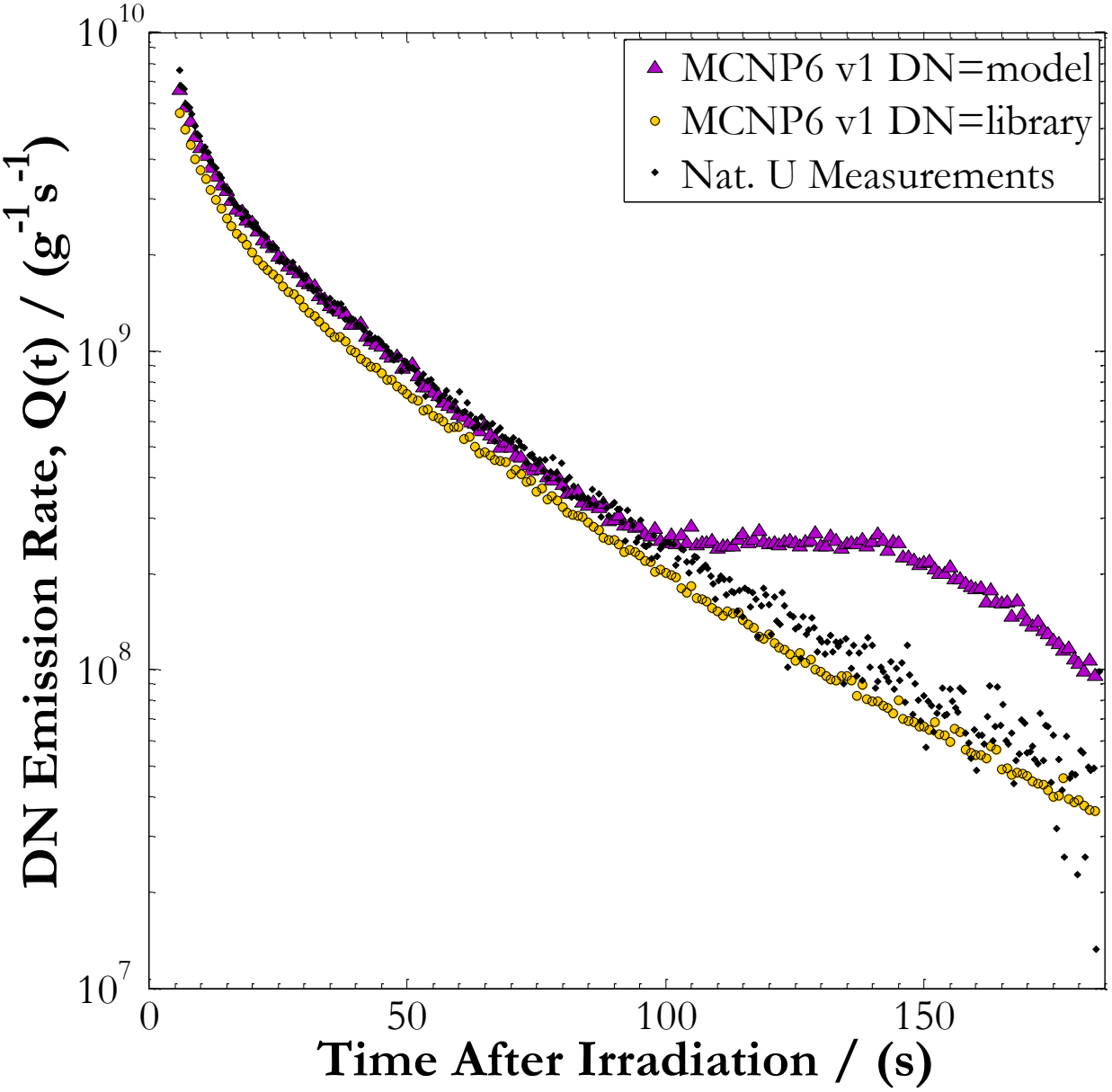

Figure 3: Delayed neutron emission rates from Nat. U measurements, model and library DN options in MCNP6v1 simulations.

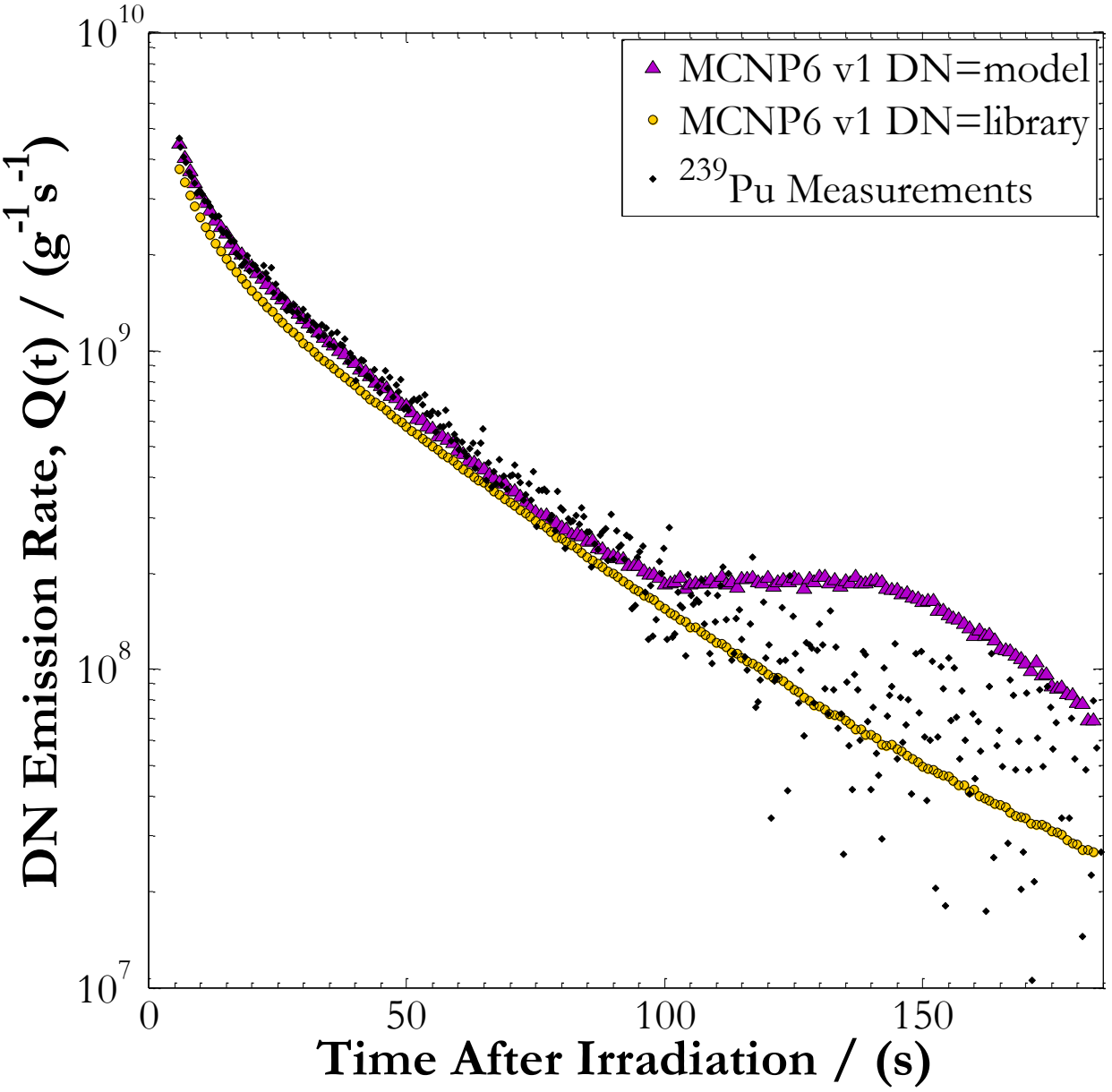

Figure 4: Delayed neutron emission rates from ^{239}Pu measurements, model and library DN options in MCNP6v1 simulations.

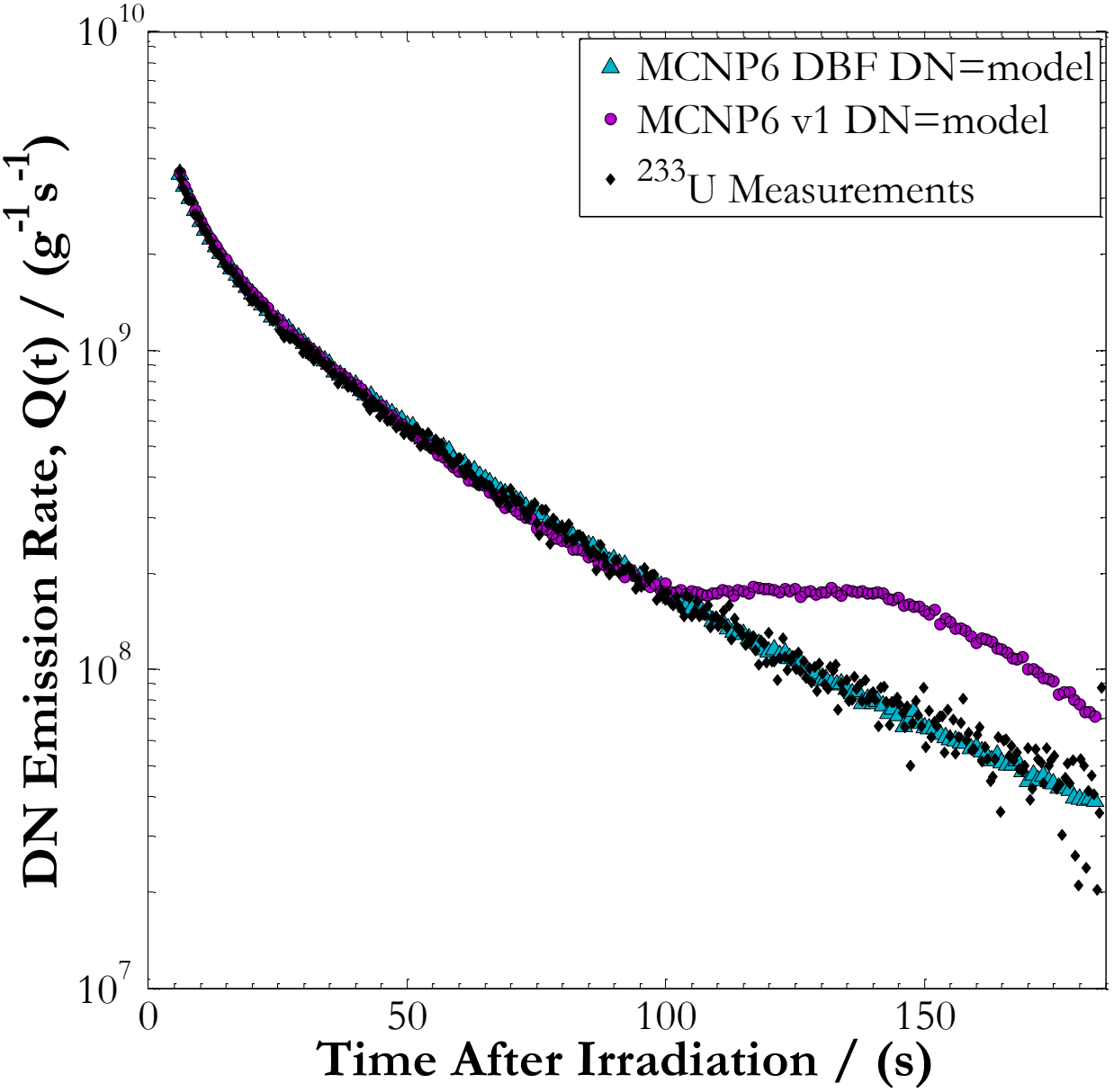

Figure 5: Delayed neutron emission rates from ^{223}U measurements, DN=model simulations with MCNP6v1 and a modified MCNP6 executable with a delayed bin fix (DBF).

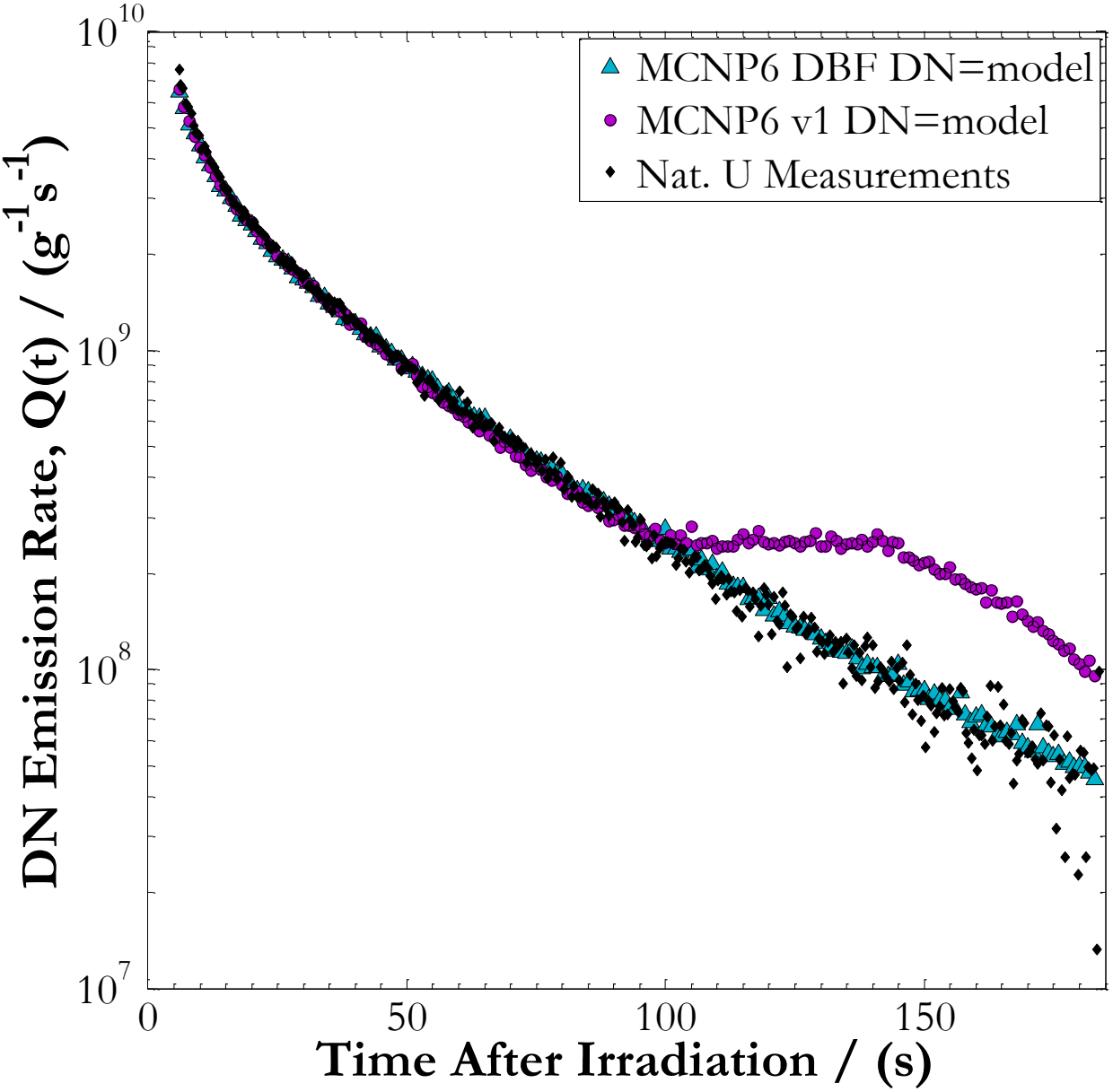

Figure 6: Delayed neutron emission rates from nat. U measurements, DN=model simulations with MCNP6v1 and a modified MCNP6 executable with a delayed bin fix (DBF).

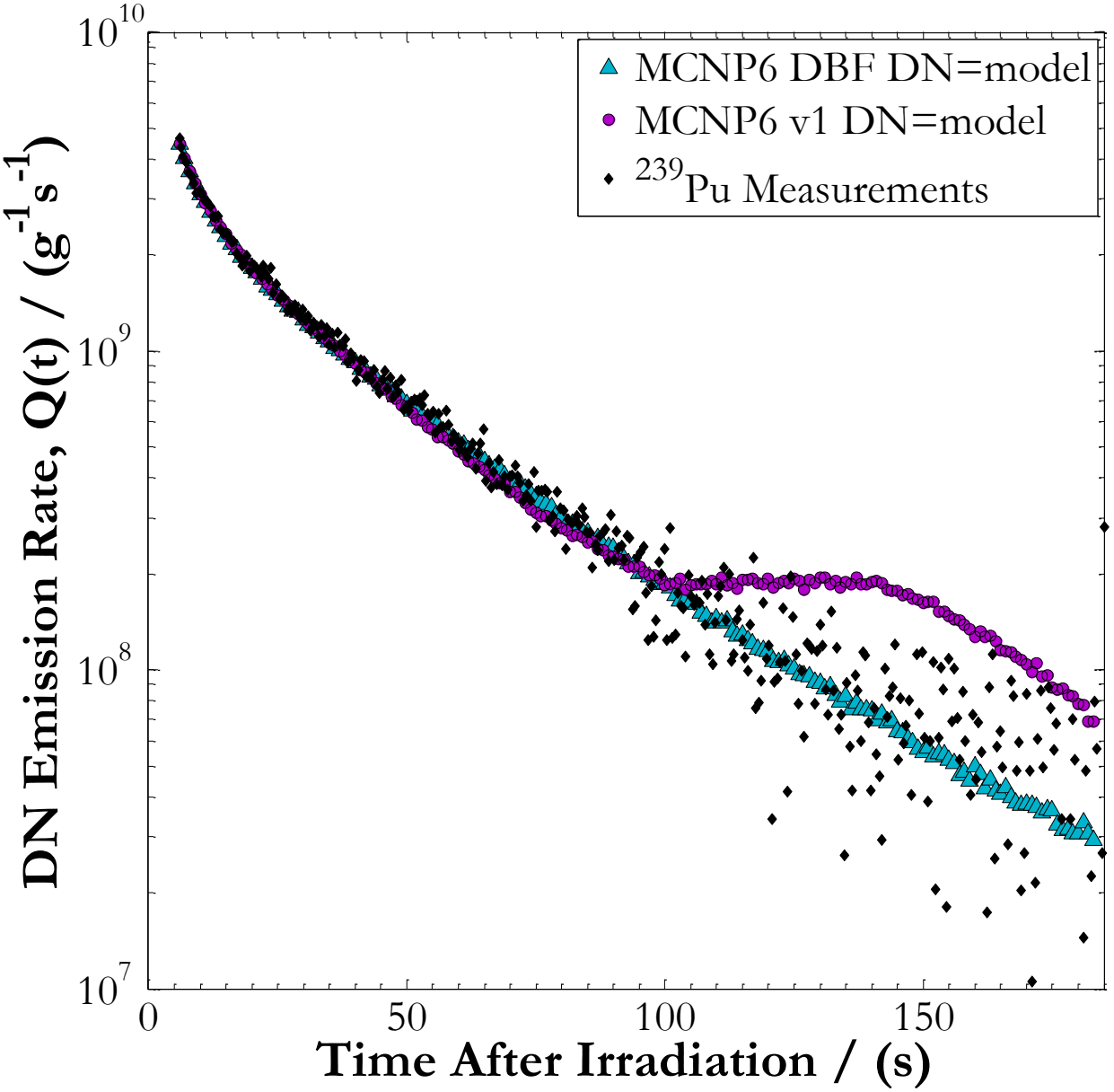

Figure 7: Delayed neutron emission rates from ^{239}Pu measurements, DN=model simulations with MCNP6v1 and a modified MCNP6 executable with a delayed bin fix (DBF).

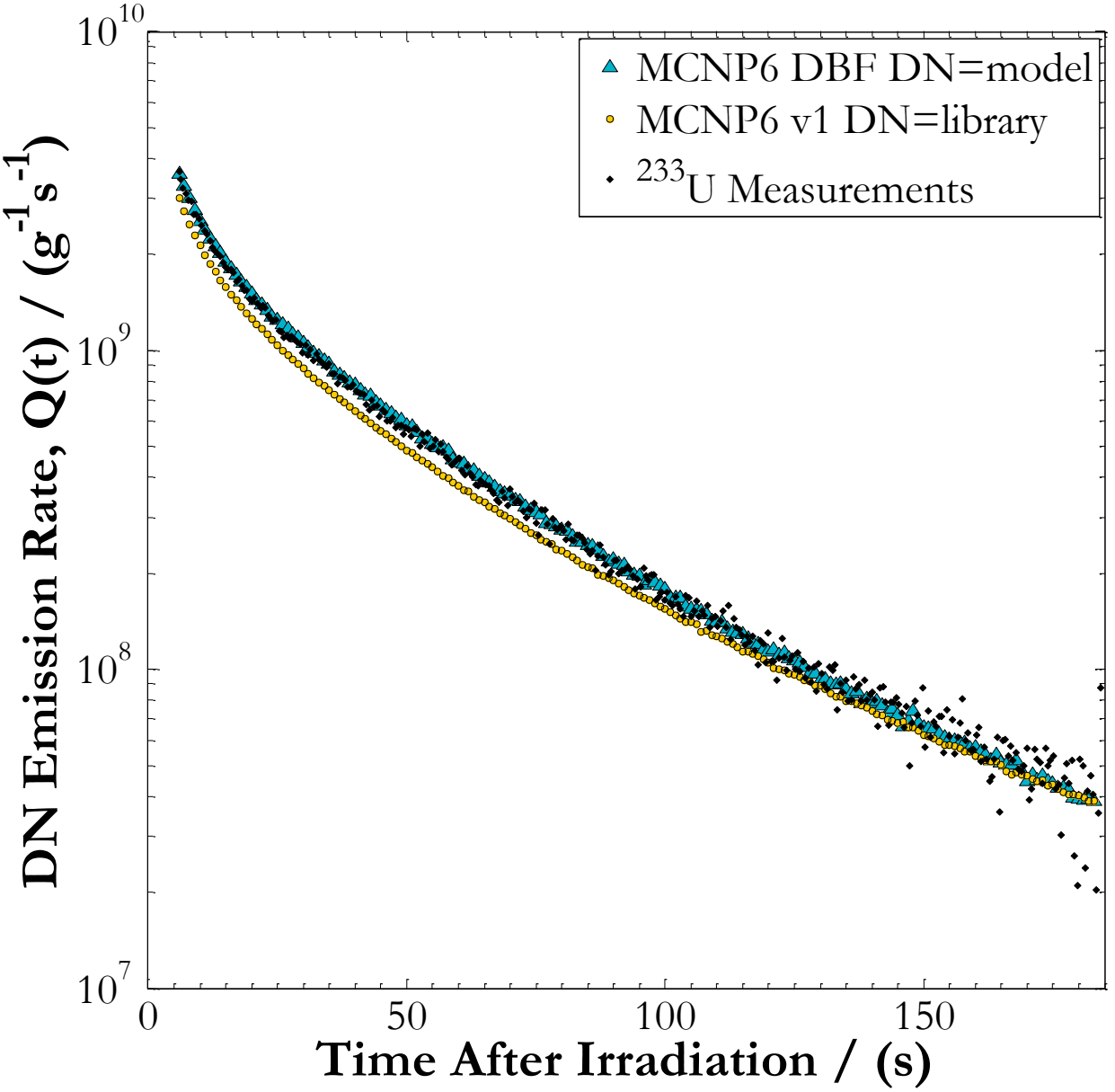

Figure 8: A comparison of delayed neutron emission rates from ^{223}U measurements, MCNP6v1 with DN=library and a modified MCNP6 executable with a delayed bin fix (DBF) and DN=model option selected.

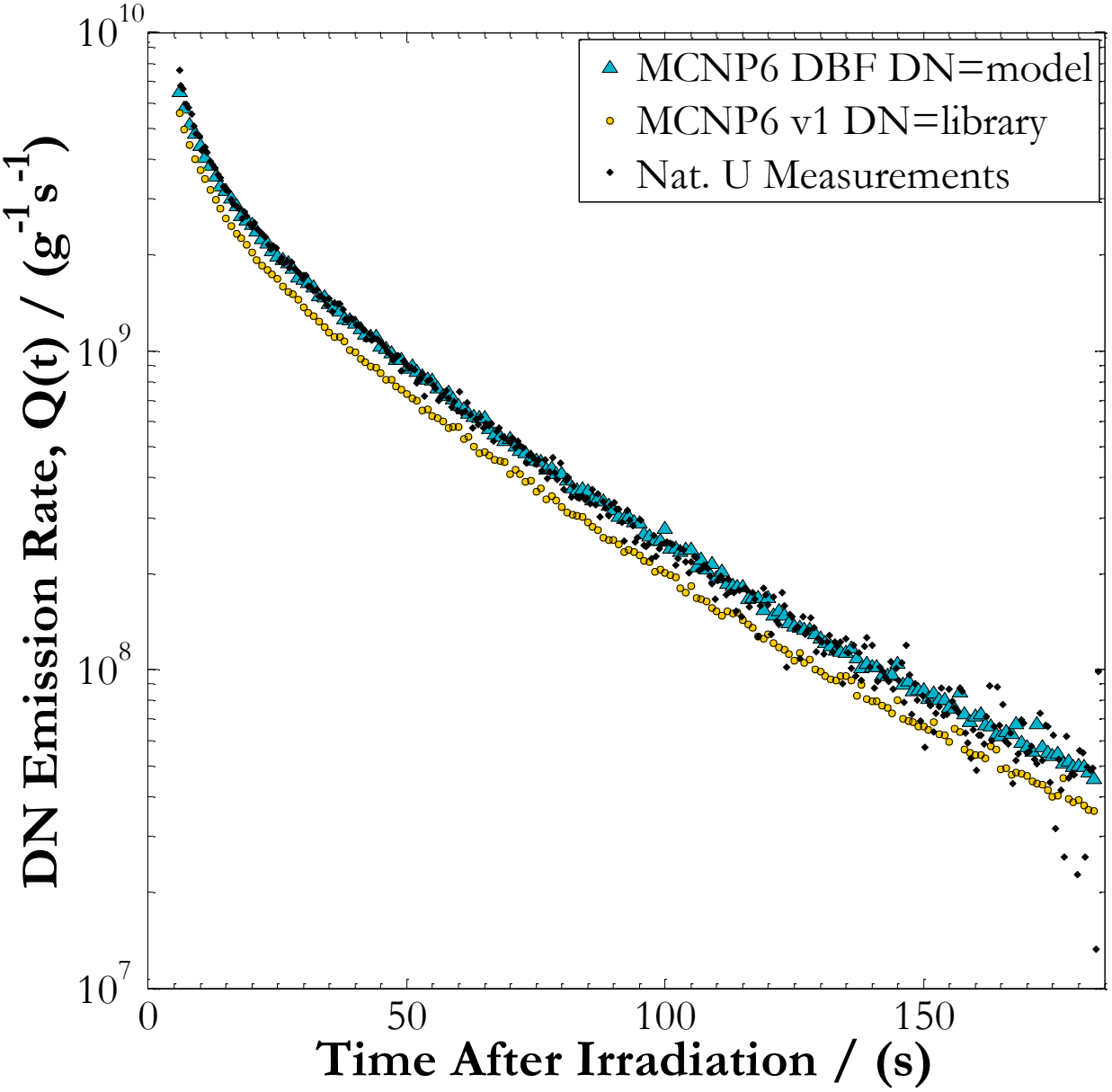

Figure 9: A comparison of delayed neutron emission rates from nat. U measurements, MCNP6v1 with DN=library and a modified MCNP6 executable with a delayed bin fix (DBF) and DN=model option selected.

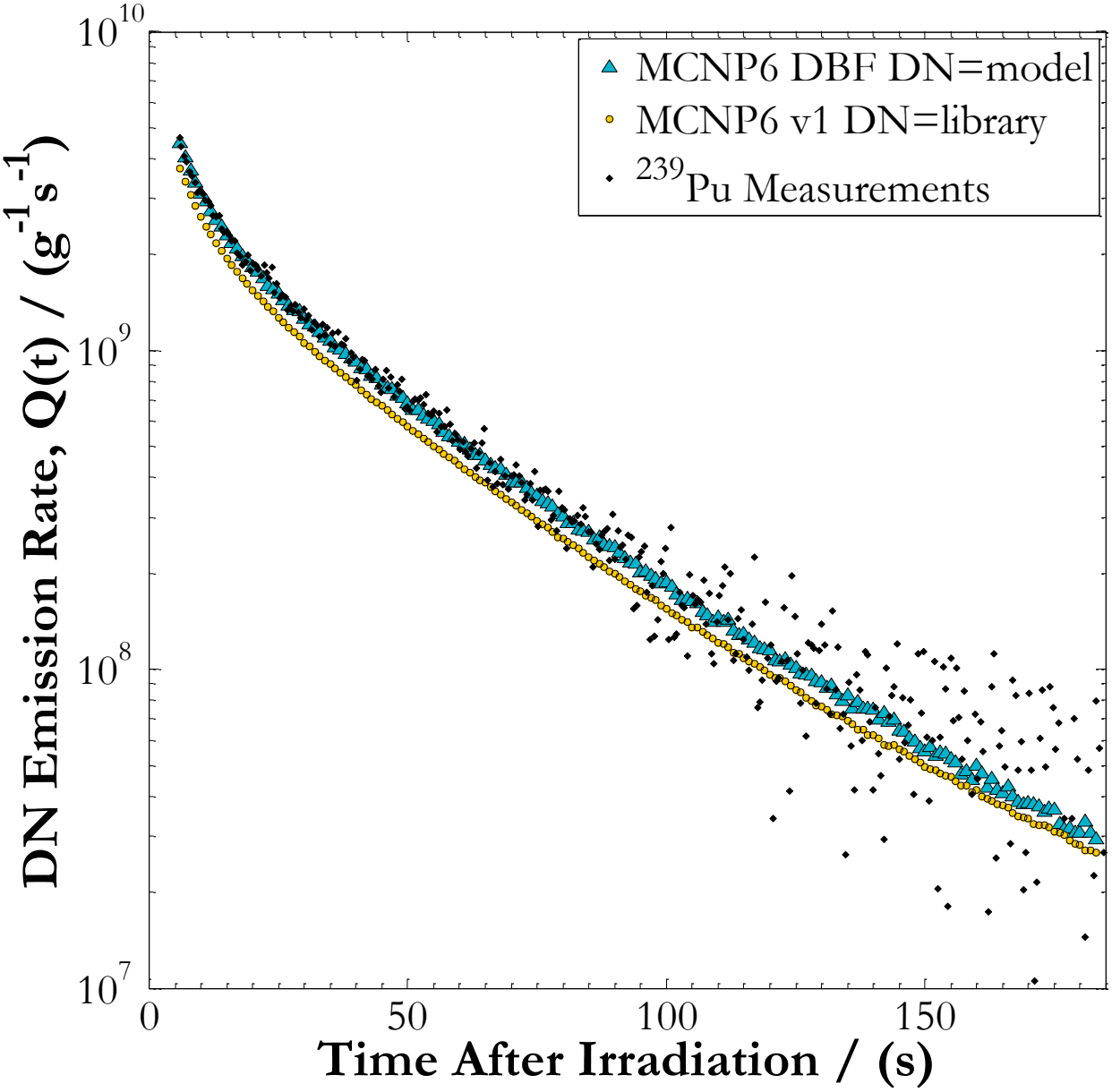

Figure 10: A comparison of delayed neutron emission rates from ^{239}Pu measurements, MCNP6v1 with DN=library and a modified MCNP6 executable with a delayed bin fix (DBF) and DN=model option selected.

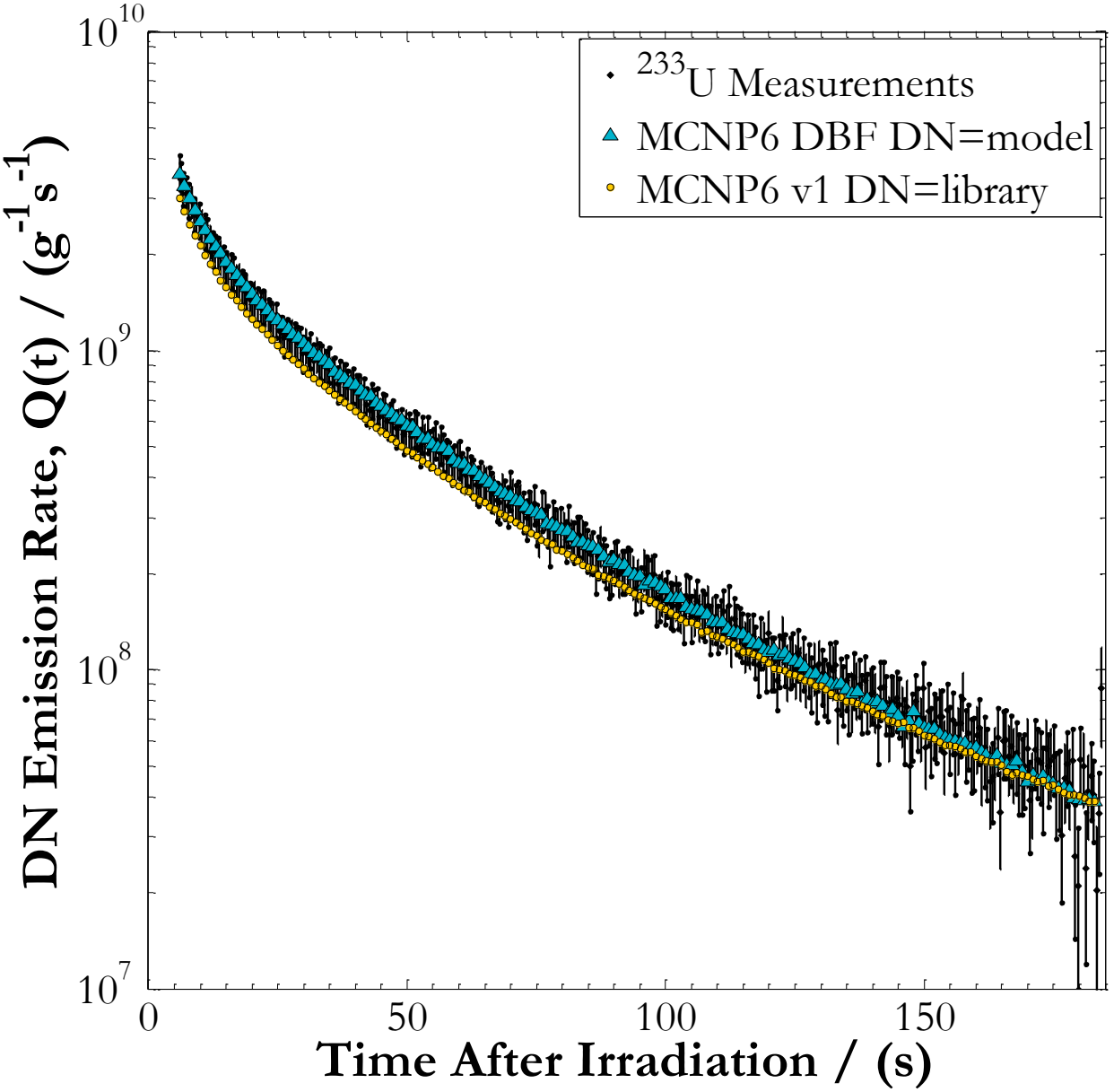

Figure 11: Delayed neutron emission rates from ^{233}U measurements, MCNP6v1 with DN=library, and a modified MCNP6 executable with a delayed bin fix (DBF) with DN=model simulations. Error bars represent 95 % confidence intervals.

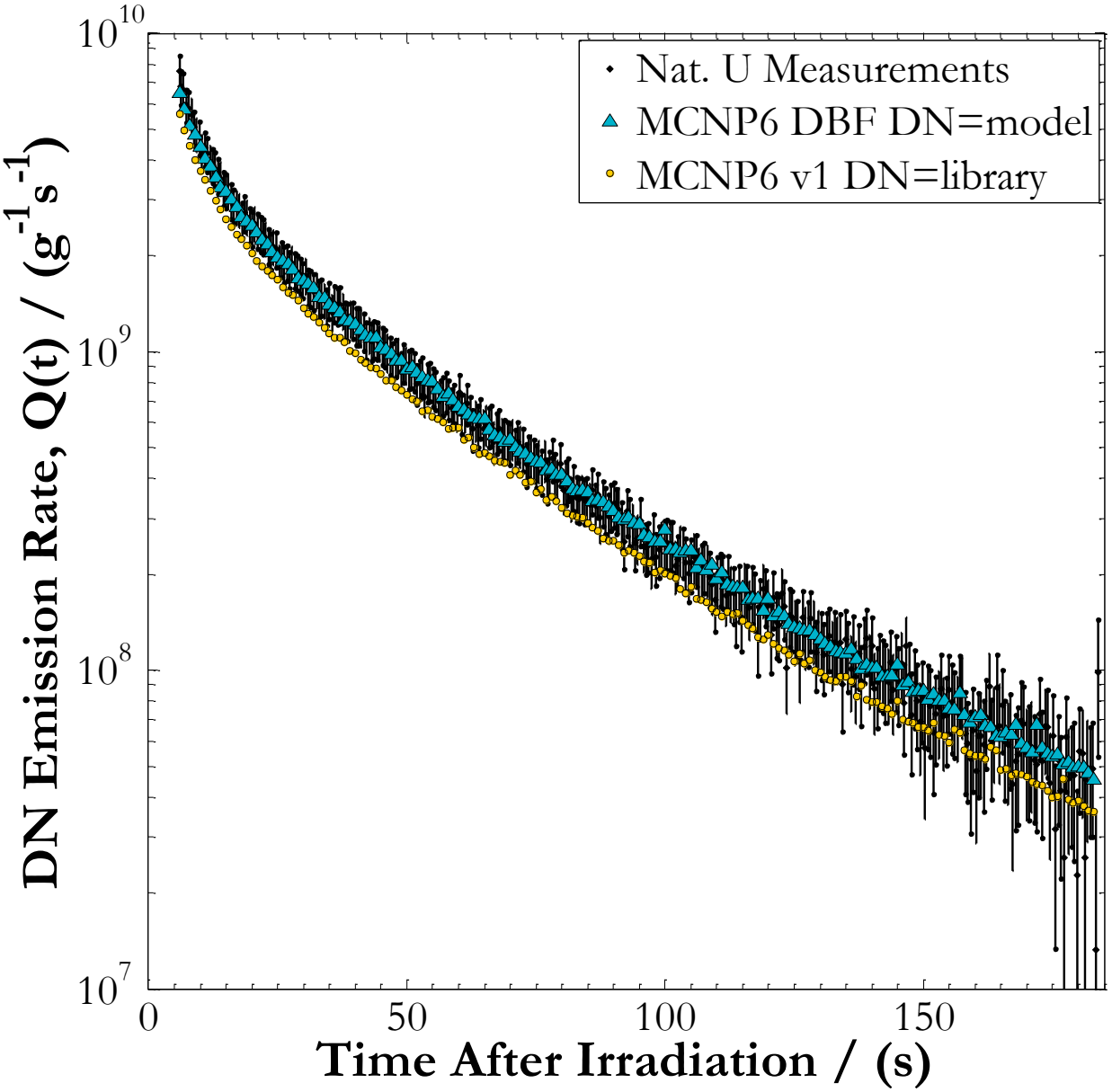

Figure 12: Delayed neutron emission rates from natural U measurements, MCNP6v1 with DN=library, and a modified MCNP6 executable with a delayed bin fix (DBF) with DN=model simulations. Error bars represent 95 % confidence intervals.

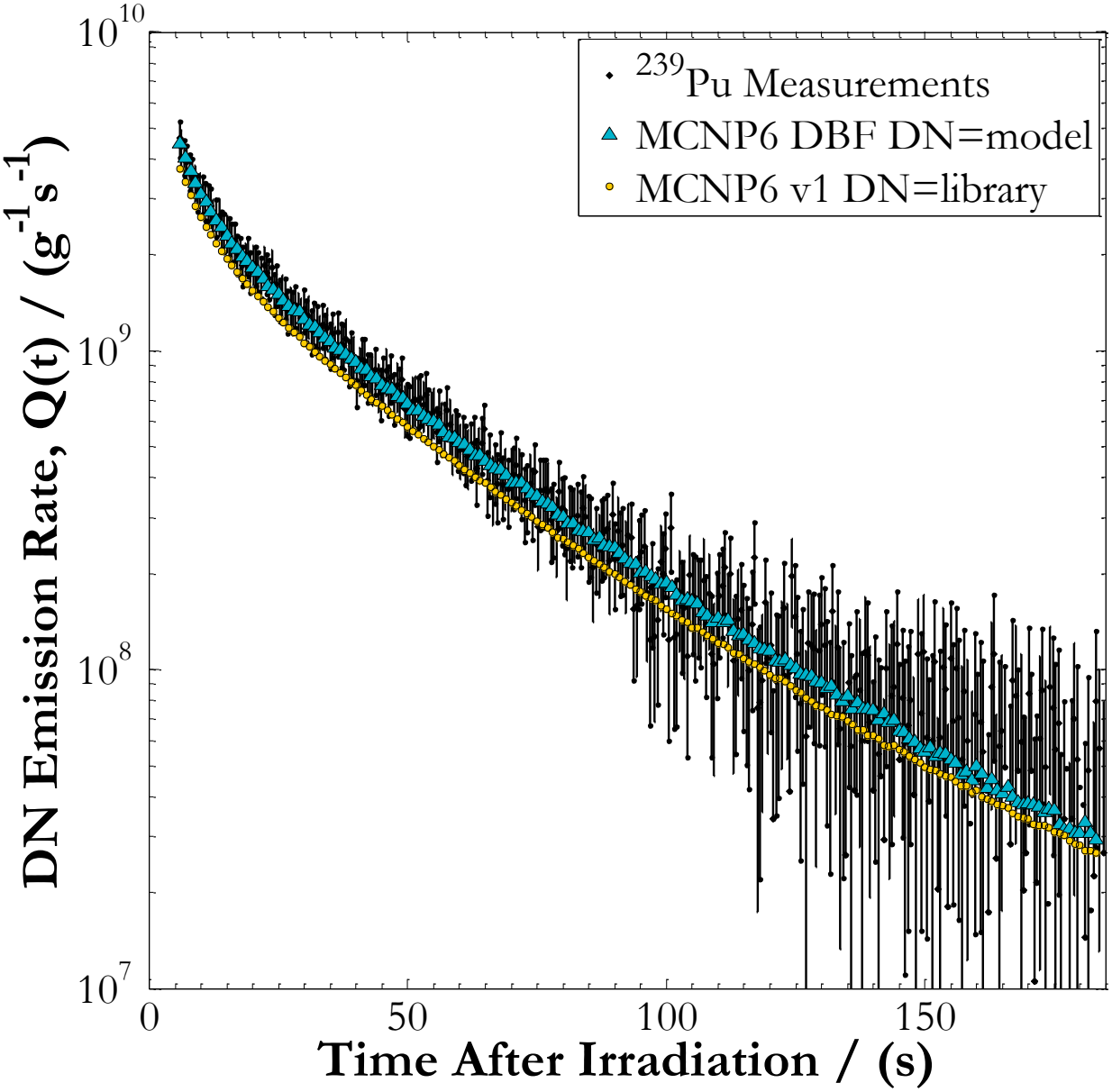

Figure 13: Delayed neutron emission rates from ^{239}Pu measurements, MCNP6v1 with DN=library, and a modified MCNP6 executable with a delayed bin fix (DBF) with DN=model simulations. Error bars represent 95 % confidence intervals.

References

1. J.T. Goorley *et al.* "Initial MCNP6 Release Overview," *Journal of Nuclear Technology* **180** 3 (2012) 298 - 315

2. M.T. Andrews, J.T. Goorley, E.C. Corcoran, D.G. Kelly. "Modeling the detection of delayed neutron signatures in MCNP6 and comparisons ^{233}U, ^{235}U and ^{239}Pu Measurements" *Journal of Nuclear Technology* **187** 3 (2014).

3. M.T. Sellers, D.G Kelly, and E.C. Corcoran, "An automated delayed neutron counting system for the mass determination of special nuclear materials" *Radioanalytical and Nuclear Chemistry* **291** 2 (2012) 281 – 285.

4. M.T. Sellers, E.C. Corcoran, D.G. Kelly, "The analysis and attribution of the time-dependent neutron background resultant from sample irradiation in a SLOWPOKE-2 reactor" *Radioanalytical and Nuclear Chemistry* **295** 2 (2013) 1221-1228.

5. T.S. Nguyen, G.B. Wilkin, and J.E Atfield "Monte Carlo Calculations Applied to SLOWPOKE Full Reactor Analysis" *AECL Nuclear Review,* **1** 2 (2012) 43-46.

6. R.A. Weldon, M.L. Fensin, G.W. McKinney, "Testing the Delayed Gamma Capability in MCNP6" *Los Alamos National Laboratory Technical Report,* LA-UR-14-22630 (2014).